X-17352

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BNL-1339

Subject Category: PHYSICS

UNITED STATES ATOMIC ENERGY COMMISSION

SERIAL REPORTS ON START-UP EXPERIMENTS. NO. 3. THE SUBCRITICAL BAROMETRIC COEFFICIENT OF THE BNL REACTOR

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February 1, 1951

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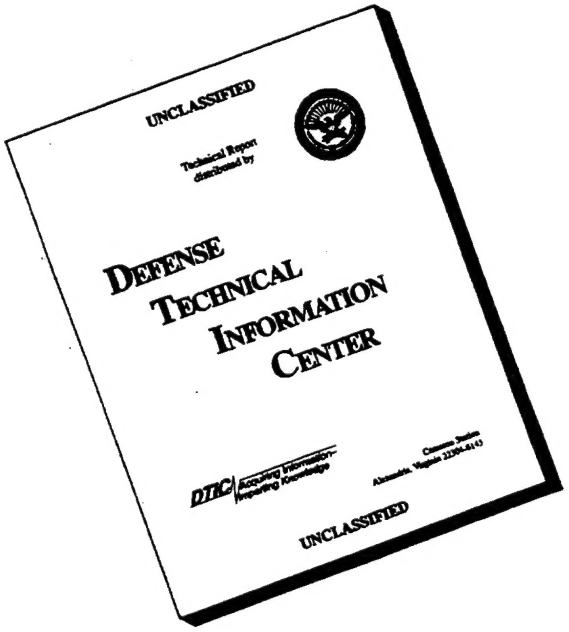

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Work performed under Contract No. AT-30-2-Gen-16.

Date Declassified: November 14, 1955.

Printed in USA, Price 15 cents. Available from the Office of Technical Services, Department of Commerce, Washington 25, D. C.

SERIAL REPORTS ON START-UP EXPERIMENTS

#3. The Subcritical Barometric Coefficient of the BNL Reactor

By J. Chernick and I. Kaplan

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Introduction.

The steady neutron level of the subcritical BNL reactor varies as S/1-k where the source term S is due principally to the spontaneous fission of U^{238} and the factor 1/1-k is contributed by the successive neutron generations created by multiplication of the primary source. As k approaches 1, the neutron level is greatly increased and becomes quite sensitive to small changes in barometer, reactor temperature, etc. The measurement of the barometric coefficient of the subcritical reactor was not originally on our experimental program but on the evening of August 23, 1950, while the reactor was temporarily idle at a loading of 387 channels, the opportunity of conducting this experiment arose. The period of the reactor, measured at 17:00 EST was - 350 sec. The reactor thus lacked 11.7 inhours of being critical and the neutron level could be expected to vary by about 10% during a normal night run. The power output of the reactor was therefore followed until the morning of August 24. The run was discontinued at 05:30 EST due to the pressure of more urgent work.

As far as could be determined from reactor instruments the variation in the neutron level of the reactor during the experiment was entirely due to barometric changes. Graphite and metal temperatures were

read frequently but little detectable changes in the thermocouple readings were recorded. The Meteorology group cooperated by delivering accurate barometric data. Weather conditions for the experiments were normal. A change of 1.5 mm Hg in total pressure was recorded during the night and 3.8 mm in the partial nitrogen pressure, the larger change in nitrogen pressure being due to variations in humidity.

Theoretical Estimate of Barometric Coefficient

About 10% of the volume of the BNL reactor is taken up by voids due to cooling channels, experimental holes and the central gap. In addition, the graphite structure is porous as is indicated by the fact that the absolute density of graphite is 2.25 while the bulk density of the reactor graphite is 1.69. Thus 25% of the remaining volume is theoretically pore volume. The pores are quite small, the data of Fortunatow and Rabinowitch[1] indicating that two-thirds of the pores are less than 10^{-6} cm in radius. Experiments have shown that not all the pores are accessible to gases. G.N.Thomas[2], using short graphite cylinders of various diameters, found that the fraction of the theoretical pore volume that was accessible decreased from 0.92 to 0.80 for a range of rod diameters from 8 mm to 5 cm respectively. Although there have been no experiments on larger blocks of graphite, it is safe to assume that from 25 to 30% of the volume of the BNL reactor is more or less accessible to atmospheric nitrogen.

The experiments of Thomas and others show also that the degassing of graphite at any fixed temperature is a relatively slow process (of the order of an hour) and that temperatures of about 1000°C are required for complete degassing. It appears likely then, that in addition to the initial response of a reactor to a barometric change there will be a delayed effect due to the slow rate of diffusion of nitrogen through the graph

pores. An additional delay occurs in the response of the reactor itself, the delay being of the order of the reactor period. In the present experiment the reactor period was about six minutes and the effect was not serious.

The loss of reactivity caused by the presence of nitrogen in the reactor can be estimated from the formula

$$\delta k = - K_d W F$$

where W is the relative weight of nitrogen compared to uranium, K_d is its danger coefficient and the factor F corrects for the fact that the nitrogen acts at a higher average flux level. With currently accepted cross-sections,

$$K_d = \frac{1.86}{7.15} \times \frac{238.1}{14.01} = 4.42 .$$

On the basis of 30% void volume, $W = 1.02 \times 10^{-3}$ and we estimate that $F \approx 1.2$. Hence $k = -5.4 \times 10^{-3} = -208$ inhours. The "theoretical" barometric coefficient is therefore -0.36 inh/mm N_2 or -0.27 inh/mm Hg. Previous experimental determinations of the barometric coefficient have been higher but of similar magnitude.

The value of 1.86 barns which we have used in obtaining the danger coefficient of nitrogen is based on the value obtained with the Oak Ridge pile oscillator. The old value of the danger coefficient given in the Chicago Handbook is somewhat lower (4.0) and is based on an absorption cross-section of 1.7 b at 0.025 ev. It is interesting to note that Columbia neutron spectrometer studies have consistently given larger absorption cross-sections for nitrogen. Thus Melkonian, Havens and Rainwater[3] find $\sigma_{capture}$ = 3.0 b at 0.025 ev by assuming that the $E^{-1/2}$ term in the experimental formula $\sigma_{thermal} = (9.6 + 0.48\ E^{-1/2})$ barns per nitrogen atom is entirely

due to capture. They attribute the larger cross-section to the fact that they use a gaseous rather than a solid sample in their experiments. If this is true, the difference between our estimate of 0.27 inh/mm Hg for the barometric coefficient and experimental values of about 0.4 inh/mm Hg can be reconciled.

Diurnal Variation of Nitrogen in Air

Although the barometric coefficient of a reactor has always been expressed in terms of total atmospheric pressure, the effect on reactivity can be attributed only to the nitrogen content of the air. Because of humidity changes, the proportion of nitrogen in the atmosphere can vary significantly with time. Typical diurnal variations recorded at the Meteorology station at Brookhaven during a low pressure regime in August are shown in Fig. 1. Both the total atmospheric pressure and partial nitrogen pressure were read at this station every half hour during the present experiments and were then corrected to reactor height. The correlation with the neutron level of the reactor is shown in Fig. 2. The correlation with barometer is apparent from the curves although a much longer run and a larger barometric change is required for precise results. The barometric effect could also be increased by loading a reactor closer to critical. One disadvantage in the latter case is the consequent increase in the reactor period.

Results of the Experiment

The decay curve of the BNL reactor at about 17:00 EST is shown in Fig. 3. The barometer reading at 17:00 was 762.58 mm Hg and the same reading was recorded at 18:00. The neutron level had decreased to background (25 counts/10 sec interval on a scale of 128) at 17:45. A ten minute precise count at this time gave 1488.0 counts.

Let n be the counts recorded per 5 minute interval on a scale of 128. Ignoring the short reactor transients we then have

$$\frac{dk}{dt} = -(744)(11.7)\,\frac{d(1/n)}{dt} = -8700\,\frac{d(1/n)}{dt}$$

with k expressed in inhours.

In Fig. 4 we have plotted the derivative curve of reactivity against time ($-\frac{dk}{dt}$ vs t) along with the derivative pressure curves. If the barometer were the only factor effecting the reactivity of the reactor, the curves should be strictly parallel. It can be seen, however, that the reactivity curve is only roughly similar to the others.

A least square fit yields a coefficient of 0.42 ± 0.13 inh/mm Hg, which is of the right magnitude. However, the correlation of reactivity with nitrogen yields a coefficient of only 0.15 inh/mm N_2 which is too small. We interpret this result to indicate that under the conditions of the experiment (no fans in operation) there was little mixing of the air within the reactor with outside air. Thus, although there was a response to changes in atmosphoric presure, the humidity of the reactor remained essentially constant.

The linear portions of the curves shown in Fig. 2 were likewise fitted by least squares. The slope obtained for the total pressure curve was 0.255 ± 0.015 mm Hg/hr and that of the neutron counting rate -7.20 ± 0.59 counts/5 min interval/hr. The value of the barometric coefficient is therefore

$$-\frac{7.2}{0.255} \times \frac{12}{700} = -0.48 \text{ inh/mm Hg}$$

with 10% precision.

Scattergrams of the neutron counting rate against atmospheric

pressure are shown in Figs. 5A and 5B. In Fig. 5B the correlation of the neutron count with the barometer reading taken 20 minutes earlier is shown. The correlation appears to be somewhat improved if such a time lag is introduced.

It is evident that the precision of the experiment could be greatly improved under better weather conditions. The reactivity changes occuring during the present experiment were very small (Fig. 4) and it is possible that small reactor temperature changes that were not picked up by the relatively insensitive recording instruments in use can account for the incomplete correlation between the barometer and neutron level of the reactor. Methods of improving the precision of the present experiment have been discussed but opportunities to repeat an experiment of this type are infrequent.

REFERENCES

1. Fortunatow and Rabinowitch. Zeit. Angew. Chem. 41, 1222 (1928).
2. F. N. Thomas, "Investigations on the Pore Structure and Degassing of Pile Graphite". AERE - C/R - 176. SECRET
3. Melkonian, Havens and Rainwater. "Neutron Beam Spectrometer Studies of Nitrogen", M - 2273. RESTRICTED

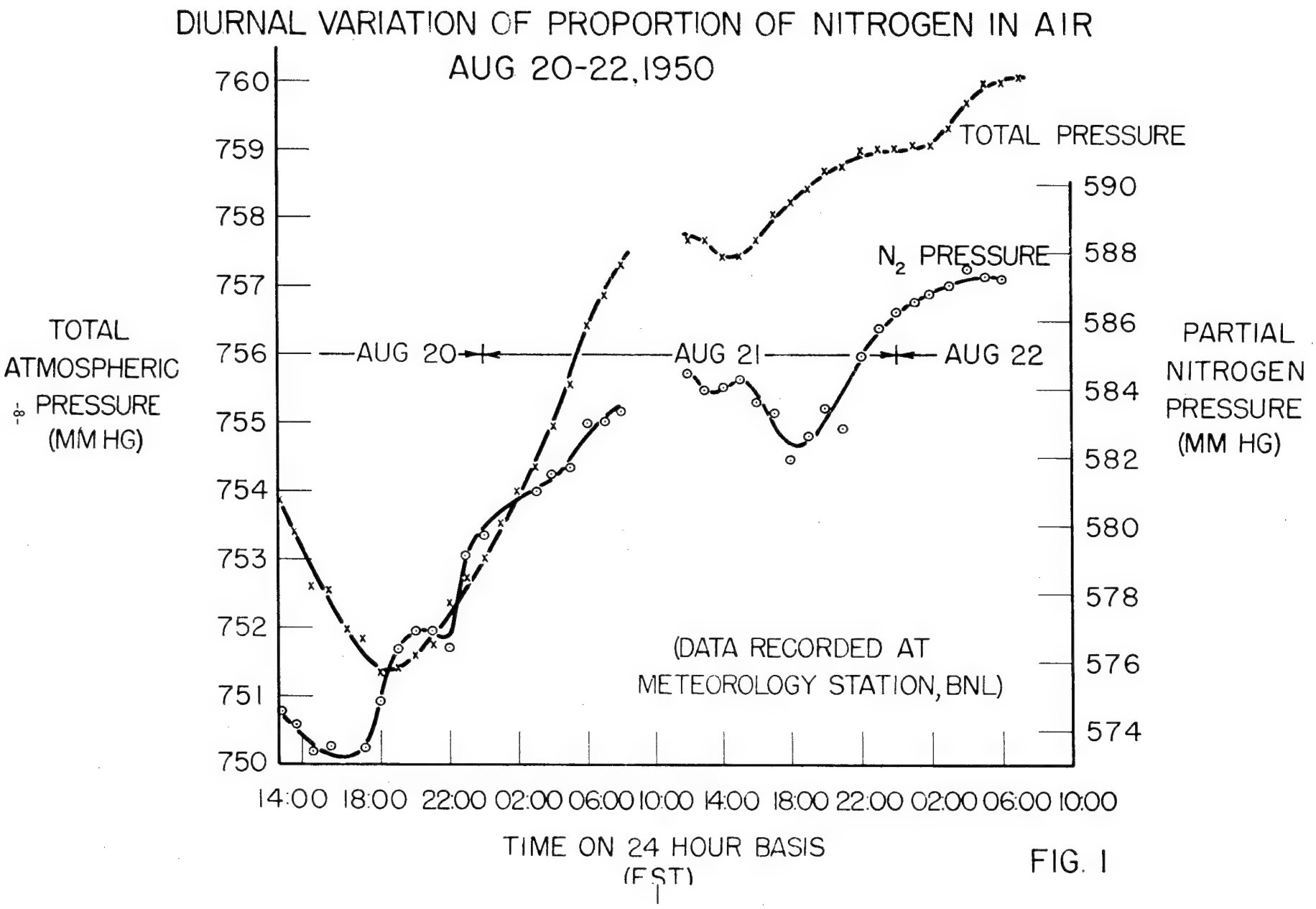

DIURNAL VARIATION OF PROPORTION OF NITROGEN IN AIR
AUG 20-22, 1950
TOTAL PRESSURE
N_2 PRESSURE
AUG 20
AUG 21
AUG 22
(DATA RECORDED AT METEOROLOGY STATION, BNL)
TOTAL ATMOSPHERIC PRESSURE (MM HG)
PARTIAL NITROGEN PRESSURE (MM HG)
760
759
758
757
756
755
754
753
752
751
750
590
588
586
584
582
580
578
576
574
14:00 18:00 22:00 02:00 06:00 10:00 14:00 18:00 22:00 02:00 06:00 10:00
TIME ON 24 HOUR BASIS (EST)

FIG. 1

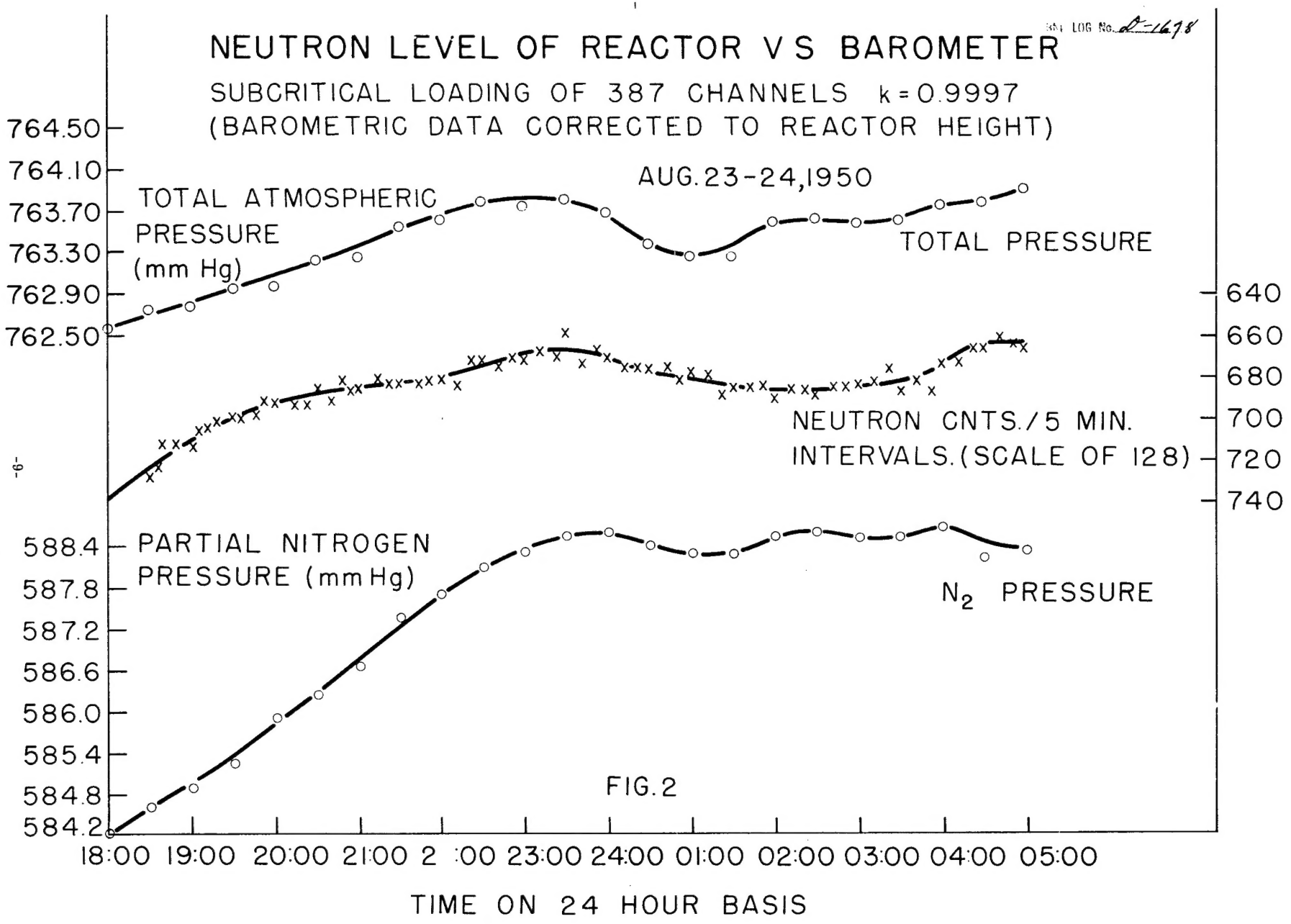


FIG. 2

DECAY OF POWER OUTPUT OF REACTOR AFTER WITHDRAWAL OF SOURCE

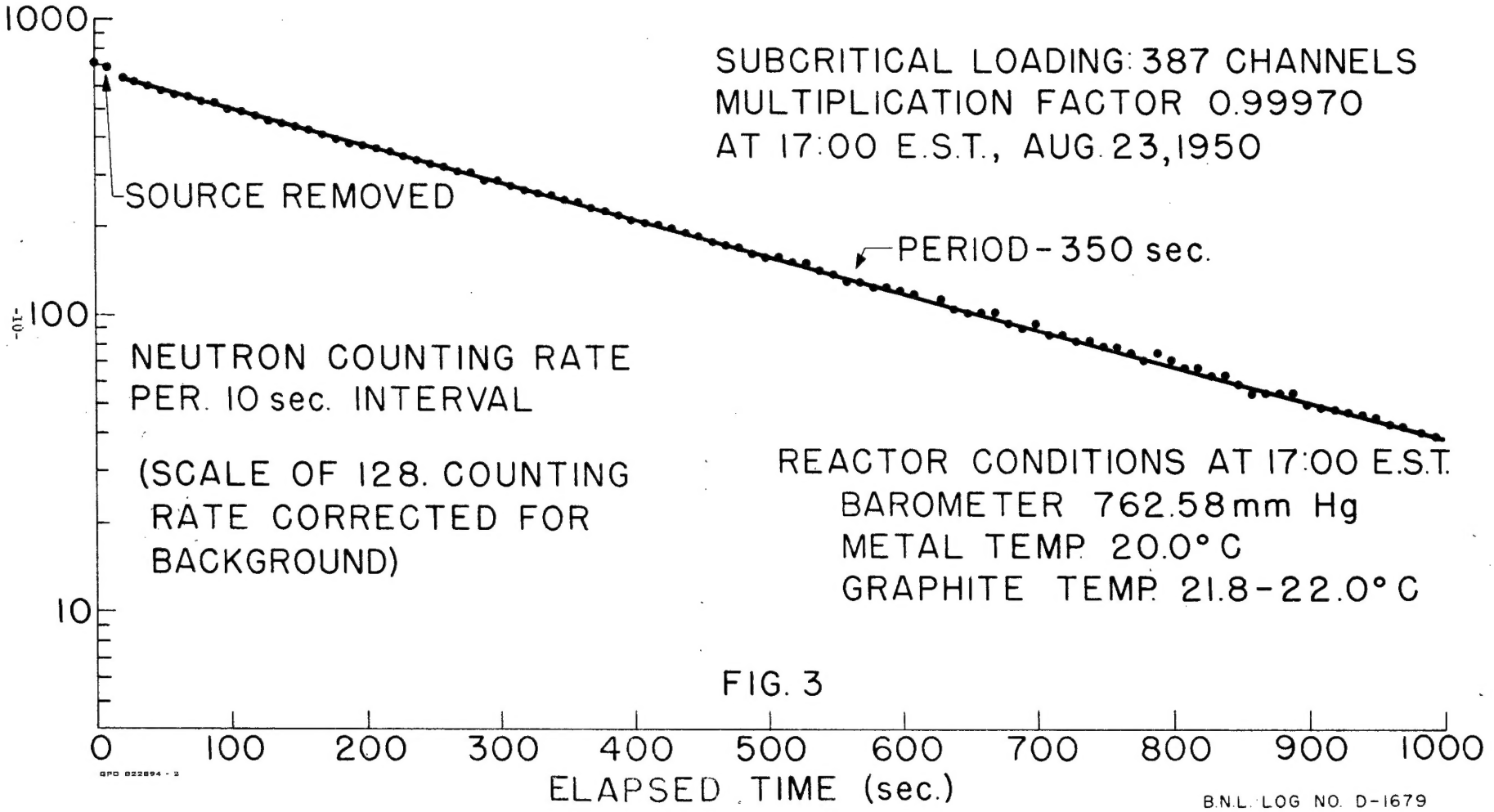


FIG. 3

GPO 822894 - 2

B.N.L. LOG NO. D-1679

DERIVATIVE CURVES OF REACTIVITY AND PRESSURE

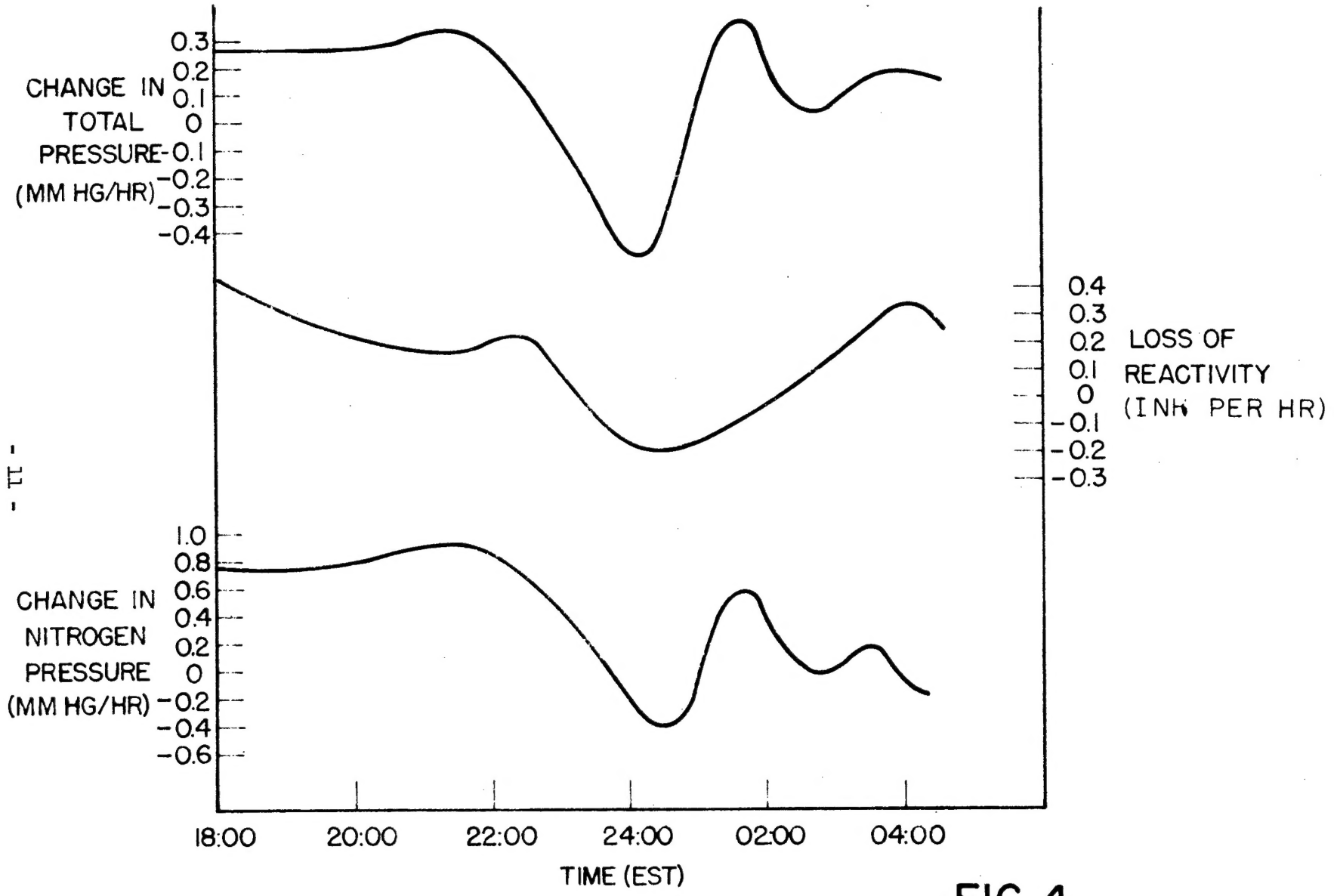
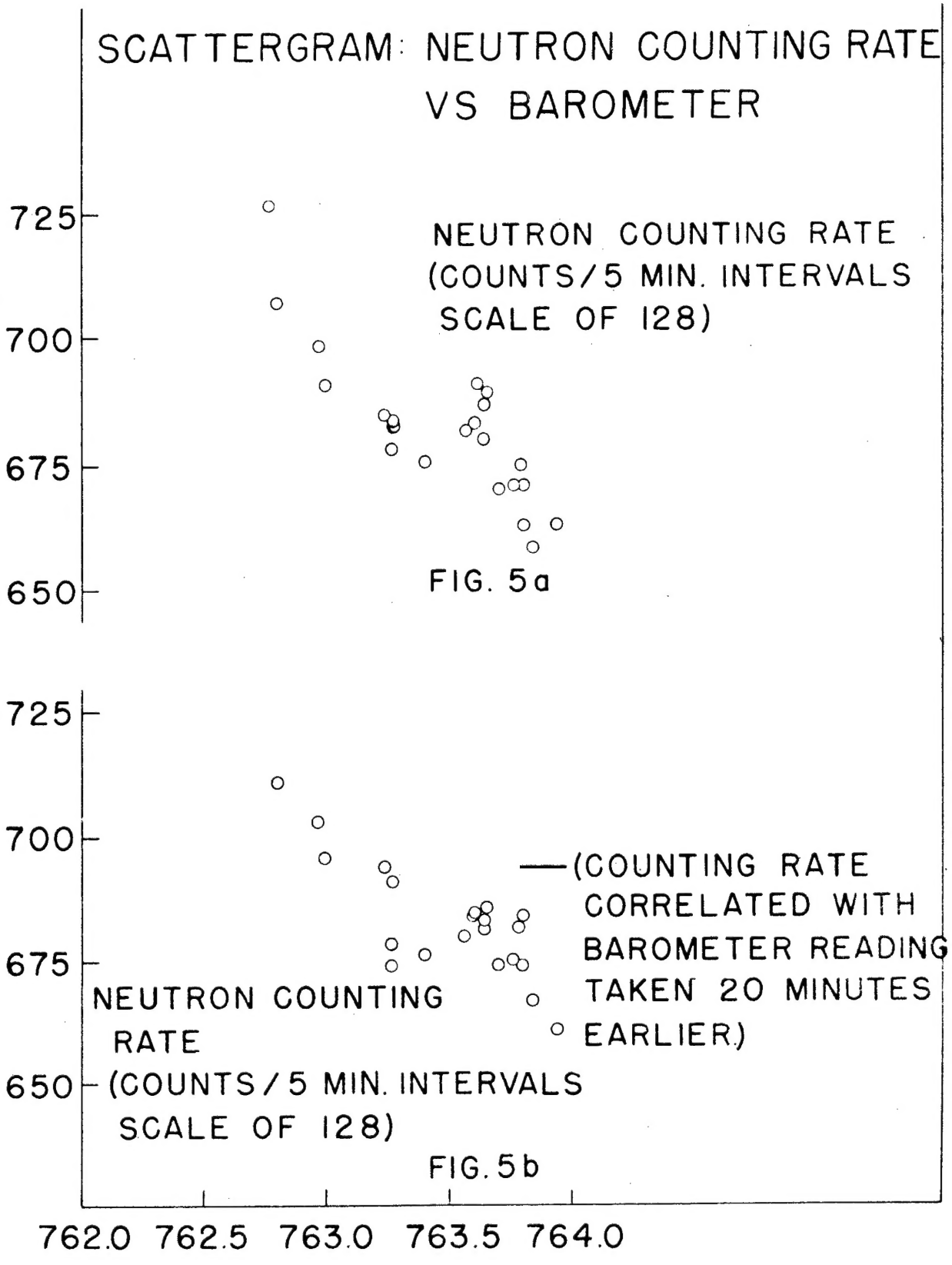


FIG. 4

B.N.L. LOG NO. D-1680


SCATTERGRAM: NEUTRON COUNTING RATE VS BAROMETER
725
700
675
650
NEUTRON COUNTING RATE (COUNTS/5 MIN. INTERVALS SCALE OF 128)
FIG. 5a
725
700
675
650
NEUTRON COUNTING RATE (COUNTS/5 MIN. INTERVALS SCALE OF 128)
—(COUNTING RATE CORRELATED WITH BAROMETER READING TAKEN 20 MINUTES EARLIER)
FIG. 5b
762.0 762.5 763.0 763.5 764.0
BAROMETER (mm Hg)

GPO 822894 - 1